MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 3, 2015/2016

EME4016 – HEAT TRANSFER

(ME)

31 MAY 2016
9.00 a.m - 11.00 a.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question Paper consists of eight pages including the cover page.
2. Answer ALL questions. Each question carries 25 Marks and the distribution of the Marks for each question is given in brackets [ ].
3. Write all your answers in the Answer Booklet provided.

Question 1

(a) A long steel plate heated to a uniform initial temperature T_i is put in a fluid at a temperature T_∞ as shown in Figure Q1a ($T_\infty < T_i$, both temperatures are in the units of Kelvin). The thickness of the plate is 6 cm. The density, specific heat, and thermal conductivity of the plate are $\rho = 8 \times 10^3$ kg/m^3, $c_p = 420$ J/kg·K, and $k = 17$ W/m·K, respectively. The heat transfer coefficient is $h = 340$ W/m^2·K.

(i) Is the use of lumped capacitance method to compute the transient temperature of the steel plate appropriate in this problem? Justify your answer. **[5 marks]**

(ii) For Fourier number, $Fo > 0.2$, the one-term approximation for a plate of thickness $2L$, is given as

$\theta^* = \theta_o^* \cos(\zeta_1 x^*)$,

where θ_o^* represents the middle plane temperature of the plate and

$\theta_o^* = C_1 \exp(-\zeta_1^2 Fo)$.

C_1 and ζ_1 are coefficients depending on Biot number.

The dimensionless variables are defined as $\theta^* = \dfrac{T - T_\infty}{T_i - T_\infty}$, $x^* = \dfrac{x}{L}$ and $Fo = \dfrac{\alpha t}{L^2}$.

Using one-term approximation, develop an expression for the total heat removed from the steel plate per unit area normal to the x axis, (J/m^2) over a period of time $t = \tau$ s in terms of ρ, c_p, L, T_i, T_∞, C_1, ζ_1, τ and α. **[10 marks]**

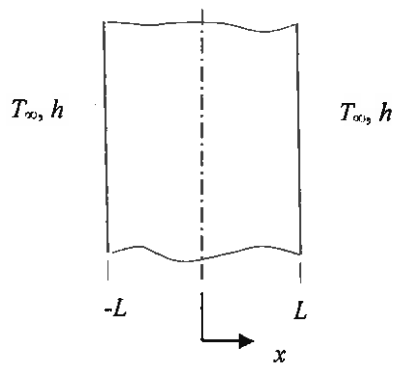

Figure Q1a

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Question 1 (Continued)

(b) Two fluids are separated by a long composite slab with an area A, normal to the x-axis consisting of two materials, A and B with known thermal conductivity, k_A and k_B as shown in Figure Q1b.The thickness of the materials are L_A and L_B respectively while the fluids are characterized by temperatures $T_{1\infty}$ and $T_{2\infty}$, and heat transfer coefficients h_1 and h_2 respectively . It is given that: $A = 0.4$ m^2, k_A = 0.75 W/m·°C, k_B = 1.50 W/m·°C , L_A = 20 mm, L_B = 30 mm, $T_{1\infty}$ = 80 °C, $T_{2\infty}$ = 20 °C, h_1 = 50 W/m^2·°C and h_2 = 25 W/m^2·°C. Assume steady-state condition and no heat generation in the composite slab.

(i) Find the interface temperature between material A and material B. **[6 marks]**

(ii) If the composite slab is replaced by a concrete slab of thermal conductivity 1 W/m·K, with thickness 50 mm, what is the rate of heat transfer if A, $T_{1\infty}$, $T_{2\infty}$, h_1 and h_2 are unchanged? **[4 marks]**

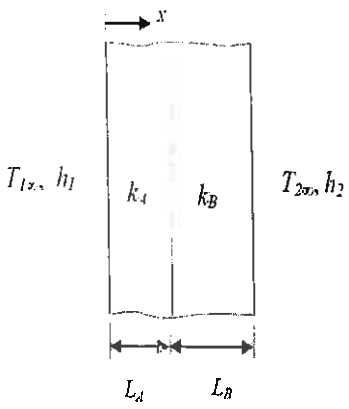

Figure Q1b

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Question 2

(a) Consider an opaque horizontal plate maintained at 900 K, its edges and lower surface are well insulated. The plate has a total hemispherical absorptivity of 0.52 and the following spectral emissivity function:

$$\varepsilon_\lambda = \begin{cases} 0.4, & 0 < \lambda < 3\,\mu\text{m} \\ 0.8, & 3\,\mu\text{m} < \lambda < \infty \end{cases}$$

(i) What is the total hemispherical emissivity of this plate at 900 K? **[7 marks]**

(ii) If the plate is subjected to an irradiation of 6000 W/m^2, determine its radiosity.

[5 marks]

(b) Evaluate the net rate of radiative heat transfer from *each* of the three *blackbody* inner surfaces of the cylindrical *enclosure* shown in Figure Q2. It is given that A_1 is at 227 °C, A_2 is at 200 °C and A_3 is at 120 °C. Length of cylinder, L = 1 m and diameter of cylinder, D =0.5 m. It is given that F_{13}= 0.06.

[13 marks]

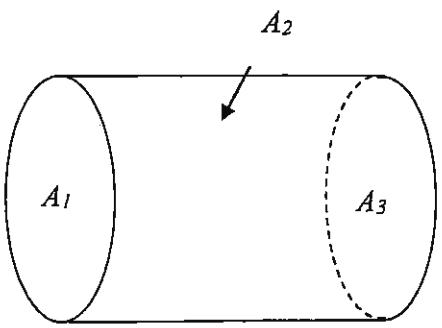

Figure Q2

Take the Stefan-Boltzmann constant as 5.67×10^{-8} W/m$^2 \cdot$ K^4 for **Question 2.**

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Question 3

(a) The local Nusselt Number, Nu_x for laminar natural convection on a vertical flat plate at uniform temperature is given by ,

$$Nu_x = \frac{h_x x}{k} = 0.443 Ra_x^{1/4}$$

where x is the distance along the plate from the leading edge.

(i) Determine the *average* Nusselt number for a surface of height L.

[6 marks]

(ii) A thin amplifier at uniform temperature 125 °C is mounted vertically in air at 35 °C. *Verify* that the flow is laminar and *determine* the heat transfer per unit width from the amplifier in W/m due to natural convection. The height of the amplifier is 40 mm. Approximate the thin amplifier as a flat plate in your calculation.

[7 marks]

(b) Air at 20 °C and 1 atm flows at a velocity of 1.5 m/s over a 0.75 m x 2 m flat plate. The plate is maintained at 140 °C. *Determine* the rate of heat transfer from the plate if the air flows parallel to the 0.75 m side. If the air flows parallel to the 2 m side, without doing further calculation, *comment* and *reason* on the rate of heat transfer in comparison to that when air flows parallel to the 0.75 m side.

[12 marks]

Local Nu number for flow over a flat plate:

Laminar flow: $Nu = 0.332 \, \mathrm{Pr}^{1/3} \, \mathrm{Re}_x^{1/2}$

Turbulent flow: $Nu = 0.0296 \, \mathrm{Pr}^{1/3} \, \mathrm{Re}_x^{4/5}$

Average Nu number for flow over a flat plate:

Laminar flow: $\overline{Nu} = 0.664 \, \mathrm{Pr}^{1/3} \, \mathrm{Re}_L^{1/2}$

Turbulent flow: $\overline{Nu} = 0.037 \, \mathrm{Pr}^{1/3} \, \mathrm{Re}_L^{4/5}$

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Question 4

Glycerin at 20 °C and 0.8 kg/s is to be heated by ethylene glycol at 60 °C in a thin-walled double-pipe parallel-flow heat exchanger. The temperature difference between the two fluids is 20 °C at the outlet of the heat exchanger. If the overall heat transfer coefficient is 240 W/m^2·°C at clean condition and the heat transfer area is 1.6 m^2, determine:

(a) the rate of heat transfer, **[8 marks]**
(b) the outlet temperature of the glycerin, and **[4 marks]**
(c) the mass flow rate of the ethylene glycol. **[6 marks]**

After a period of use, built-up scale in the heat exchanger gives a fouling factor of 0.0004 m^2·°C /W, discuss the effects of fouling on

(d) (i) the rate of heat transfer and **[3 marks]**
(ii) mass flow rate of ethylene glycol if the inlet temperatures of each fluid stream in the heat exchanger, the temperature difference at the outlet, the mass flow rate of glycerin and the heat transfer area are unchanged. **[4 marks]**

The specific heat capacity for glycerin is c_p =2400 J/kg·°C and

the corresponding value for ethylene glycol is c_p =2500 J/kg·°C.

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APPENDIX 1: Properties of air

Properties of air at 1 atm pressure

Temp., T, °C	Density, ρ, kg/m^3	Specific Heat, C_p, J/kg · °C	Thermal Conductivity, k, W/m · °C	Thermal Diffusivity, α, m^2/s	Dynamic Viscosity, μ, kg/m · s	Kinematic Viscosity, ν, m^2/s	Prandtl Number, Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-6}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
90	0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
100	0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
120	0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
140	0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
160	0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
180	0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
200	0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
250	0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
300	0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935
350	0.5664	1056	0.04721	7.892×10^{-5}	3.101×10^{-5}	5.475×10^{-5}	0.6937
400	0.5243	1069	0.05015	8.951×10^{-5}	3.261×10^{-5}	6.219×10^{-5}	0.6948
450	0.4880	1081	0.05298	1.004×10^{-4}	3.415×10^{-5}	6.997×10^{-5}	0.6965
500	0.4565	1093	0.05572	1.117×10^{-4}	3.563×10^{-5}	7.806×10^{-5}	0.6986
600	0.4042	1115	0.06093	1.352×10^{-4}	3.846×10^{-5}	9.515×10^{-5}	0.7037
700	0.3627	1135	0.06581	1.598×10^{-4}	4.111×10^{-5}	1.133×10^{-4}	0.7092
800	0.3289	1153	0.07037	1.855×10^{-4}	4.362×10^{-5}	1.326×10^{-4}	0.7149
900	0.3008	1169	0.07465	2.122×10^{-4}	4.600×10^{-5}	1.529×10^{-4}	0.7206
1000	0.2772	1184	0.07868	2.398×10^{-4}	4.826×10^{-5}	1.741×10^{-4}	0.7260
1500	0.1990	1234	0.09599	3.908×10^{-4}	5.817×10^{-5}	2.922×10^{-4}	0.7478
2000	0.1553	1264	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

Note: For ideal gases, the properties C_p, k, μ, and Pr are independent of pressure. The properties ρ, ν, and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Keenan, Chao, Keyes, Gas Tables, Wiley, 198; and Thermophysical Properties of Matter, Vol. 3, Thermal Conductivity, Y. S. Touloukian, P. E. Liley, S. C. Saxena, Vol. 11: Viscosity, Y. S. Touloukian, S. C. Saxena, and P. Hestermans, IFI/Plenun, NY, 1970, ISBN 0-306057020-8.

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APPENDIX 2: Numerical values of the function $F(0 \rightarrow \lambda)$

λT (μm · K)	$F_{(0 \rightarrow \lambda)}$	λT (μm · K)	$F_{(0 \rightarrow \lambda)}$
200	0.000000	9,500	0.903085
400	0.000000	10,000	0.914199
600	0.000000	10,500	0.923710
800	0.000016	11,000	0.931890
1,000	0.000321	11,500	0.939959
1,200	0.002134	12,000	0.945098
1,400	0.007790	13,000	0.955139
1,600	0.019718	14,000	0.962898
1,800	0.039341	15,000	0.969981
2,000	0.066728	16,000	0.973814
2,200	0.100888	18,000	0.980860
2,400	0.140256	20,000	0.985602
2,600	0.183120	25,000	0.992215
2,800	0.227897	30,000	0.995340
3,000	0.273232	40,000	0.997967
3,200	0.318102	50,000	0.998953
3,400	0.361735	75,000	0.999713
3,600	0.403607	100,000	0.999905
3,800	0.443382		
4,000	0.480877		
4,200	0.516014		
4,400	0.548796		
4,600	0.579280		
4,800	0.607559		
5,000	0.633747		
5,200	0.658970		
5,400	0.680360		
5,600	0.701046		
5,800	0.720158		
6,000	0.737818		
6,200	0.754140		
6,400	0.769234		
6,600	0.783199		
6,800	0.796129		
7,000	0.808109		
7,200	0.819217		
7,400	0.829527		
7,600	0.839102		
7,800	0.848005		
8,000	0.856288		
8,500	0.874608		
9,000	0.890029		

$$F(0 \rightarrow \lambda) \equiv \frac{1}{\sigma T^4} \int_0^{\lambda} E_{\lambda,b}\, d\lambda$$

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